PCT/DK 2004/000389

BEST AVAILABLE COPY

REC'D 09 JUL 2004
WIPO PCT

Kongeriget Danmark

Patent application No.: PA 2003 00856

Date of filing: 06 June 2003

Applicant: GN Resound A/S
(Name and address) Maarkærvej 2A
DK-2630 Taastrup
Denmark

Title: A hearing aid wireless network

IPC: H 04 R 25/00

This is to certify that the attached documents are exact copies of the above mentioned patent application as originally filed.

PRIORITY DOCUMENT
SUBMITTED OR TRANSMITTED IN COMPLIANCE WITH RULE 17.1(a) OR (b)

Patent- og Varemærkestyrelsen • Kongeriget Danmark

Patent- og Varemærkestyrelsen
Økonomi- og Erhvervsministeriet

07 July 2004

Susanne Morsing
Susanne Morsing

A HEARING AID WIRELESS NETWORK

The present invention relates to a hearing aid wireless network for wireless interconnection of hearing aids, a remote control for a hearing aid, etc.

Wireless communication between a hearing aid and its remote control is well known in the art. For example US 2002/0044669 discloses a hearing aid in which different sets of parameters can be stored in a memory for adapting the signal-processing unit to different hearing situations. External transmitters are provided, which are installed in preferred places where the person wearing the hearing aid goes, such as the living room, the workplace, etc. Each transmitter automatically emits a transmitter-specific signal, which allows the hearing aid to make a definite assignment of the signal to a hearing situation in which the transmitter is located. The signal can be received only in the immediate vicinity of the transmitter. Hereby the hearing aid is adapted automatically to different hearing situations without having to carry out an error-prone signal analysis of the microphone signals or having to operate the hearing aid manually.

Likewise, in binaural hearing aids it is well known to exchange signals between the hearing aids through a wireless communication channel. In the human hearing system, binaural hearing ability, i.e. the ability to localize sound sources in space, results from a complicated signal processing of sounds arriving at the left and right ears, in which the amplitudes, phase difference, and frequency distributions of the received sounds are crucial. In order to preserve the binaural hearing ability, the output of a hearing aid must be based on processing of sound as received at both ears and thus, it is required that signals are exchanged between two hearing aids. For example WO 99/43185 discloses a binaural hearing aid system comprising two hearing aid units for arrangement in a user's left and right ear, respectively. A bi-directional communication link is provided between the units. The bi-directional communication link may be wireless.

The known wireless communication links for hearing aids are point-to-point communication links.

It is an object of the present invention to provide a hearing aid wireless network facilitating interconnection of a plurality of units in the network, such as hearing aids, remote controllers, fitting instruments, mobile phones, headsets, door bells, alarm systems, broadcast systems, such as tele coil replacement, etc, etc.

According to the invention the above and other objects are fulfilled by provision of a hearing aid comprising a radio for communication with a plurality of other units in a wireless network.

The radio may operate according to a frequency division multiplex scheme (FDM) wherein the frequency range utilized by the network is divided into frequency channels, and different units in the network communicate in specific respective frequency channels.

Alternatively, the radio may operate according to a time division multiplex scheme (TDM) wherein the time is divided into numbered time slots and different units in the network communicate in specific respective time slots.

The radio may also operate according to a combined FDM and TDM scheme.

Preferably, the radio operates according to a frequency diversification or spread spectrum scheme, i.e. the frequency range utilized by the network is divided into a number of frequency channels, and transmissions switch channels according to a predetermined scheme so that transmissions are distributed over the frequency range. According to the present invention, a frequency hopping algorithm is provided that allows units in the network to calculate what frequency channel the network will use at any given point in time without relying on the history of the network.

Preferably, one unit in the network is a master unit. All other units in the system synchronize to the timing of the master unit, and preferably, the master unit is a hearing aid, since the hearing aid user will always carry the hearing aid when he or she will use the network.

Every unit in the network has its own identification number, e.g. a 32-bit number. Globally unique identities are not required since the probability of two users having hearing instruments with identical identifications is negligible.

Preferably, a new unit is automatically recognized by the network and interconnected with the network.

It is an advantage of a network operating according to a spread spectrum scheme that the communication has a low sensitivity to noise, since noise is typically present in specific frequency channels, and communication will only be performed in a specific channel for a short period before it switches to another channel.

Further, several networks may co-exist in close proximity, for example two or more hearing aid users may be present in the same room without network interference,

since the probability of two networks simultaneously using a specific frequency channel will be very low.

Likewise, the hearing aid network may coexist with other wireless networks utilizing the same frequency band, such as Bluetooth networks or other wireless local area networks.

In the following, the invention will be further explained with reference to the drawing wherein:

Fig. 1 schematically illustrates a hearing aid according to the present invention coupled to a wireless network,

Fig. 2 illustrates slots and frames,

Fig. 3 illustrates slot timing,

Fig. 4 illustrates common transmission/reception processing,

Fig. 5 illustrates data transmission processing and packet assembling,

Fig. 6 illustrates data reception processing,

Fig. 7 illustrates data exchange of an initial acquisition process,

Fig. 8 illustrates data exchange during a hearing aid acquisition process,

Fig. 9 illustrates data exchange during a connection negotiation process,

Fig. 10 illustrates the timing of a hearing aid acquisition process,

Fig. 11 illustrates in more detail two of the frames of Fig. 6,

Fig. 12 illustrates details of communication of LMP packets of Fig. 6,

Fig. 13 illustrates a half frame slave scan, and

Fig. 14 is a blocked schematic of a radio according to the invention.

Fig. 1 schematically illustrates a binaural hearing aid with a left ear hearing aid and a right ear hearing aid, each of which has a radio enabling communication with a plurality of other units in a wireless network. In the example illustrated in Fig. 1, a doorbell, a mobile phone, a cordless phone, a TV-set, and a fitting instrument is also connected to the wireless network.

The illustrated embodiment of the invention operates in the 2.4 GHz industrial scientific medical (ISM) band. It comprises 80 frequency channels of 1 MHz bandwidth. A frequency hopping TDM scheme is utilized.

As shown in Fig. 2, the time is divided into so-called slots that have a length of 1250 μs (twice the length of a minimum Bluetooth™ slot). The slots are numbered from 0 to 255.

256 slots, i.e. slot 0 to slot 255 constitute a frame. Frames are also numbered.

Among factors influencing the SLOT length, is the required lower latency of the system and to have a relatively low overhead with respects to headers and PLL locking. As a compromise, the slot length has been chosen as a multiple of 625 μS. In order to aid (i.e. not prevent) that the proposed protocol can be implemented on BLUETOOTH™ enabled devices.

Each slot (except slot 128) is used for transmission by one specific device. This prevents data collisions inside the network. Any slave unit may transmit data in slot 128 and hence collisions may occur in this slot.

The data structure of a slot is illustrated in Fig. 3. The basic unit for sending data between devices in a network is a packet. A packet consists of a header, payload data, and CRC checksums. The CRC checksum only allows determining, if (some) bit errors have occurred (packet integrity), not to do error correction. If error correction is required, this must be implemented at a higher layer.

The duration of a symbol (1 bit) is 1μs.

The performance of the proposed system is: Lowest latency is 1.25 μs. Highest bandwidth is approximately 730 kb/s

A SYNC word is used to detect the start of a packet in a slot (or if there is a packet). All devices know a single SYNC word.

Each unit has a free running symbol, slot and frame counter. The slot and frame counters of a slave unit are synchronized with the respective counters of the master unit of the network.

During data communication, the frequency channel is changed for each slot, hence 800 frequency hops are performed every second. The hopping sequence is defined by a very long pseudo random sequence known by all units connected to the network (it is calculated, not listed). The sequence is a function of the identification number (ID) of the master device, hence it allows several distinct networks to co-exist.

The power consumption of units in a wireless network depends on the bandwidth and latency. Typically, large bandwidth and low latency lead to high power consumption.

The bandwidth of the illustrated embodiment is 730 kb/s (using maximum sized data packets in every slot). The bandwidth can be optimized for each application by selecting a number of slots that has the required aggregated bandwidth.

Due to the slot structure, the theoretically lowest latency of the system is 1.25 ms (using every slot).

Due to the slot structure, the theoretically lowest response time of the system is 2.5 ms. The response time is defined as the time from one device sends a request and it gets a reply from another device.

In Fig. 4, processing common for transmission and reception of data is illustrated. The frequency channel, synchronization word, and the slot/frame number to be utilized have to be determined.

The frame/slot counter is a 40-bit counter wherein the lowest significant 8 bits is the slot number (SLOT_CNT) and the most significant 32 bits is the frame number (FRAME_CNT). In the master unit, the frame/slot counter is free running. In a slave unit, the frame/slot counter is synchronized to the slot 0 link management packet. The SYNC correlation timing performs this synchronization. Thus, the timing of the master unit controls packet timing, and all slaves synchronize to the master.

The RF frequency-hopping channel (CHAN) is generated by a pseudo random number generator. The seeding value is based on:

- The master identification number (MST_ID) whereby different networks (e.g. two sets of hearing aids in the same area) use different sequences to substantially eliminate interference between different sets of hearing aids.
- The slot number (SLOT_CNT) so that each slot utilizes a different frequency channel.
- The frame number (FRAME_CNT) so that a new sequence is utilized in each frame, i.e. to avoid that slot 0 utilizes the same frequency channel in every transmission.

The frequency channel number (CHAN) generation algorithm does not require storage of previous channel numbers, i.e. there is no memory in the algorithm. The next channel number is calculated based on the current channel number. The pseudo random sequence for the frequency-hopping scheme and for generating the SYNC words is implemented as a hardware block.

Packet assembling and transmission processing is further illustrated in Fig. 5. The preamble and synchronization guard is fixed patterns. The synchronization word is either a copy of the two possible SYNC words (generation "once" by the SYNC word generation).

The rest of the packet is generated by concatenation of the packet header, the payload and the CRC of the payload. A seed using the CHAN whitens this raw packet. The whitening is necessary to make the data as DC free as possible.

Data reception processing is further illustrated in Fig. 6. The receiver searches for a packet by correlating against the known SYNC word (MST_SYNC or LMP_SYNC). If the correlation succeed the bit timing and the placement in time of the first bit after the SYNC is known. The PREAMB and SYNCGUARD are just ignored.

The header and payload fields are first de-whitened using the CHAN.

The different fields of the raw packet are "copied" out and checked for errors.

The whitening algorithm is implemented in hardware and is a linear feedback shift register (LFSR).

The Error checking algorithm protocol (at the base band level) does NOT implement forward error correction. The ONLY error checking performed is on the SLOTNUM and PKTLEN fields in the header, and using a CRC-16 checksum on the data part of the payload. If additional error checking or correction of the data part is needed this MUST be implemented in the application layer.

Acquisition is the process of establishing a network, i.e. that the devices find each other. The acquisition time is the time it takes for a device to connect to a network.

An acquisition method that consumes low power and still is "fast" has been developed.

Table 1 Acquisition times

Acquisition mode	Time	Description
Initial acquisition	0s - 10.2s (5.1s average)	When a new network is established, e.g. when two hearing instruments are powered on try to establish a network.
Acquisition into existing network	0s - 82s (41s average)	When a network is already establish a new device tries to enter the network
High Power acquisition	0s - 2.56s (1.28s average)	Same as above, but this mode is VERY power consuming and cannot be used for ZnO_2 batteries (but excellent for e.g. a remote control)

To explain the hearing aid acquisition process timings diagrams of two hearing aids in acquisition is shown in Figs. 6-12.

This process is used at network creation and when new devices try to detect the presence of an existing network. Acquisition is achieved when a device successfully receives a link management packet in slot "0" and replies to it in slot "128".

The acquisition process has the two conflicting requirements of fast acquisition time and low power consumption (which corresponds to low radio transceiver activity). Having a special acquisition process in the hearing aids to save power solves this. Other devices can use (remote control etc.) the hearing aid acquisition or another algorithm, which takes more power and is faster.

The hearing aid acquisition is done by making an acquisition cycle of 32 frames. Within these frames the hearing aid scans (i.e. receives) in one frame. In the other frames LMP packets are transmitted with a higher rate to increase the speed of the acquisition. This is shown in Fig. 7.

With 16 LMP packets in each frame all the ACU_CHANS has been visited once within a half frame. A scan in the other device on a certain ACU_CHAN for a half frame ensures the two devices hit each other on the same channel. The frame number (0-31) with the half slot scan is generated randomly for each acquisition scan period of 32 frames (if the free running frame counters of the two hearing aid happen to be in phase). Before the half frame scan there is a frame without TX to ensure the other hearing aid can respond on the last 8 TX LMP's.

The acquisition process makes the first hearing aid, which receives a LMP packet in the half frame scan slave in the network (in Fig. 7 hearing aid 1 becomes the slave and hearing aid 2 master). After the reception of the LMP packet the hearing aid goes into the connection negotiation process shown in Fig. 8.

The LM_NULL packet received by the slave contains timing information which means the slave is synchronized from that point and can respond with a LMP packet in slot 128. This packet is LM_REGREQ that makes the master aware of the slave and the master responds with a LM_REGACK. After this point the two devices are connected. The slave continues to receive the slot 0 LMP packets from the master for synchronization purposes (and other purposes).

The hearing aid acquisition process shown in Fig. 7 assumes both hearing aid is in the acquisition state/mode, i.e. is not a part of a network. If for example one hearing aid and a remote control is in a network with the hearing aid as master. When the

second hearing aid is turned on it goes into the acquisition mode, but the master hearing aid only sends LMP_NULL packet at the normal rate. This means the acquisition in this mode takes longer time. Fig. 10 shows the whole sequence of 32 frames (ha1_frame_no: 0-31). Figs. 10-12 illustrate various parts of the timing diagram of Fig. 10 as indicated by the frame and slot numbers. The first hearing aid that does the half frame scan will receive a LMP packet. This means the maximum acquisition time is the 32-frame cycle (12.6 s) and in average about 6s. The acquisition time can be between 0s and 12.5 s depending on the timing phase between the two hearing aids.

In non-hearing aid devices, which have better battery/power capacity, an acquisition process that scans continuously for LMP_NULL packet is performed. To ensure good resistance against interference the scan channel is changed each frame.

In order to have a robust system, every device must be able to act as a master device as well as a slave device. As the network is dependent on the presence of the master device, it is required that the slaves detect and react when a master is no longer present.

When a slave has not received link management packets in slot 0 for a period of time, it must act this way:

1. The master and slave clocks may be out of sync. Hence the slave enters the "initial acquisition process" again, searching for a master.

2. If a master is not found, it assumes the role as master, and starts to transmit master link management packages.

For example, an individual used two hearing instruments and a remote control device when the network initially was created. The right hearing instrument is the master device, the left hearing instrument is a slave device and the remote control is another slave device. The individual removes the right hearing instrument (master) and leaves it behind. This will break the network for the remaining devices and they must perform network recovery (which is no different from the initial network creation) as described above.

As the signal emitted from the radio is low power, certain devices that are located far away from the master device (e.g. a doorbell) are not able to pick up the link management packets from the master, and hence not able to connect to the network. As it is desirable to have such devices, another approach is needed.

As a doorbell or a cooker timer device does not have to rely on ZnO_2 batteries as a power source, it can emit more power when transmitting and transmit for longer period of times.

A viable solution for paging devices (one directional communication) is to allocate 1 or more slots and some special channels for paging. The SYNC word used for link management packages should for simplicity also be used for these services.

If a doorbell rings it emits multiple packets back to back for several seconds. Every 'now and then', a device that should pick up communication from the doorbell sets its window for its correlator to a period equal to 1 (or more) slot(s) and listens on the allocated channels in the statically allocated slots.

A suggestion is to use radio channels 9, 49 and 79 for paging/asynchronous services. When a device want to issue a page message it will transmit for 4 seconds on each of the 3 radio channels.

In order to use the network like the tele coil is used today, the hearing instruments should be able to select between different masters. This could be done using either the remote control or buttons on the hearing instrument.

An auditorium is equipped with a power full transmitter (broadcast device), which broadcasts audio data. When a user enters the auditorium he/she forces the hearing instrument(s) to use the broadcast device as master. The broadcast device does NOT rely on receiving data from the hearing instruments (uni-directional communication), as those are equipped with low power transmitters.

Fig. 14 provides an overview of the blocks within the base-band engine. The figure also shows the major data flow in ingress and egress.

In ingress, the RF chip interface 1 sends SPI commands to the RF chip for configuration. The RF chip interface receives a data stream from the RF chip.

The correlator 2 extracts the slot and frame timing from the sync word, so that the rest of the receive chain can be synchronized. Based on this timing, the header extraction block 3 is used to analyze the packet header extracting the slot number and packet length. Any errors in the header are reported. A data de-whitening block 4 is used to de-whiten the packet data. The data is then converted to 16 bits parallel by the serial-parallel conversion block 5. The packet data is stored in an internal data buffer 6 by the data buffer interface 7. The data is then accessible to the DSP via the DSP interface 8 through the peripheral bus. A CRC check can also be performed on

the packet data 9. All internal configuration registers and results of header checks, CRC errors etc are accessible though the DSP interface.

Slot and frame counters 10 are also provided as well as a number of hardware timers 11.

The controller state machine 12 is responsible for overall timing of the base-band engine.

A gold code generator 13 provides hardware assistance to the software in order to generate gold codes used to program the sync words.

In egress, the RF chip interface 1 sends SPI commands to the RF chip for configuration.

The DSP will write a packet of data to the data buffer 6, 7 via the DSP interface 8. The packet data will have a CRC calculated via the data CRC generation block 9. The combined data payload and CRC are then converted to serial 5 and whitened 4. The packet header is constructed by the header generation block 3 and then appended to the data. The completed packet is then streamed to the RF chip by the RF chip interface 1.

While there have been described what are considered to be the preferred embodiments of this invention, it will be obvious to those skilled in the art that various changes and modifications may be made therein without departing from the invention.

CLAIMS

1. A hearing aid comprising a radio for communication with a plurality of other units in a wireless network.

2. A hearing aid according to claim 1, wherein the radio is adapted for selective operation in a plurality of frequency channels.

3. A hearing aid according to claim 2, wherein the radio is adapted for operation according to a time division multiplex scheme.

4. A hearing aid according to claim 2, wherein the radio is adapted for operation according to a frequency division multiplex scheme.

5. A hearing aid according to any of claims 2-4, wherein the radio is adapted for operation according to a spread spectrum scheme.

6. A hearing aid according to claim 5, wherein the radio is adapted for operation according to a frequency-hopping scheme.

7. A hearing aid according to claim 6, wherein a frequency hopping algorithm is provided that allows units in the network to calculate what frequency channel the network will use at any given point in time without relying on the history of the network.

8. A hearing aid according to any of the preceding claims, wherein one unit in the network is a master unit, and all other units in the network synchronize to the timing of the master unit.

9. A hearing aid according to claim 8, wherein the master unit is a hearing aid.

10. A hearing aid according to any of the preceding claims, wherein a new unit is automatically recognized by the network and interconnected with the network.

11. A remote controller for a hearing aid and adapted to communicate with a hearing aid according to any of the previous claims through the wireless network.

12. A fitting instrument for a hearing aid and adapted to communicate with a hearing aid according to any of claims 1-10 through the wireless network.

13. A mobile phone adapted to communicate with a hearing aid according to any of claims 1-10 through the wireless network.

14. A headset adapted to communicate with a hearing aid according to any of claims 1-10 through the wireless network.

15. A doorbell adapted to communicate with a hearing aid according to any of claims 1-10 through the wireless network.

16. An alarm system adapted to communicate with a hearing aid according to any of claims 1-10 through the wireless network.

17. A broadcast system adapted to communicate with a hearing aid according to any of claims 1-10 through the wireless network.

Patent- og
Varemærkestyrelsen

06 JUNI 2003

Modtaget

1/11

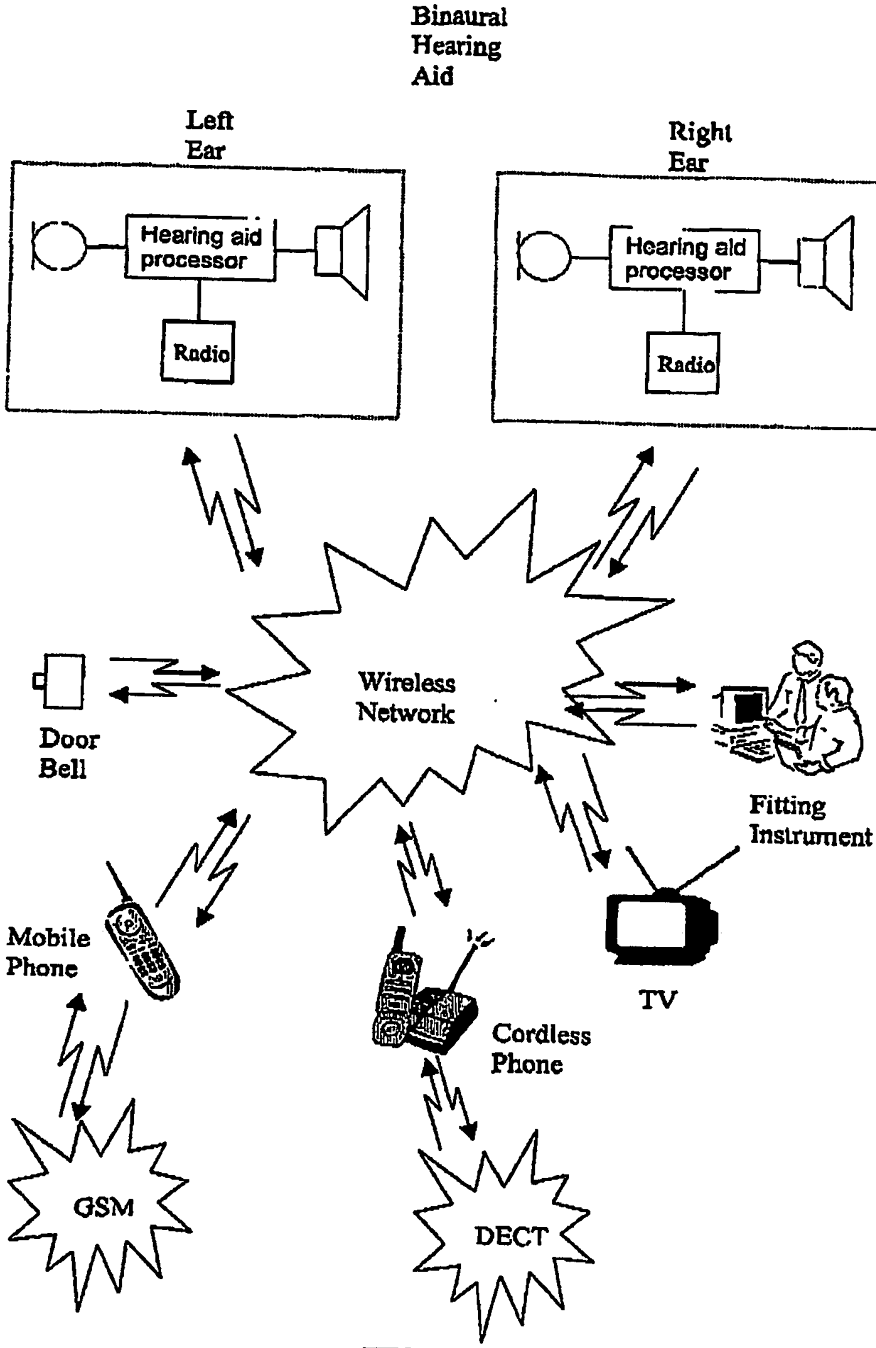

Fig. 1

Patent- og
Varemærkestyrelsen
06 JUNI 2003
Modtaget

2/11

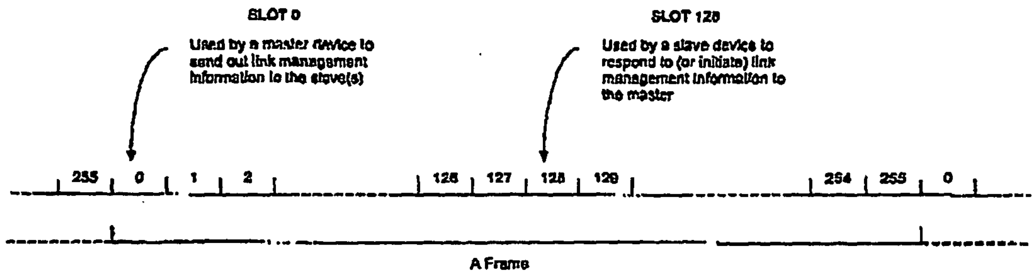

Fig. 2

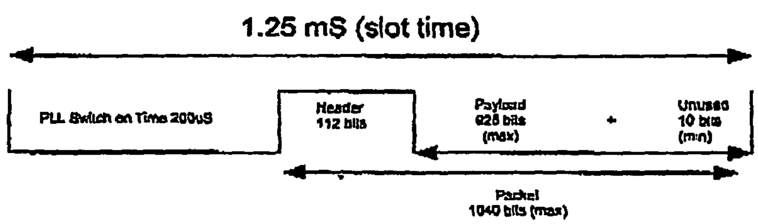

Fig. 3

Patent- og
Varemærkestyrelsen
06 JUNI 2003
Modtaget

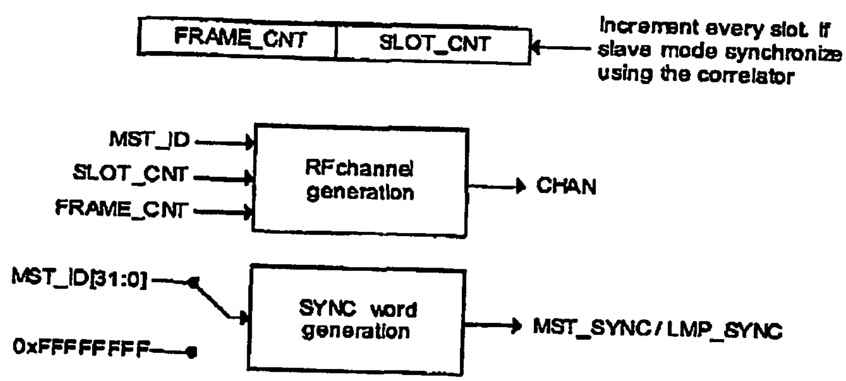

Fig. 4

Patent- og
Varemærkestyrelsen

06 JUNI 2003

Modtaget

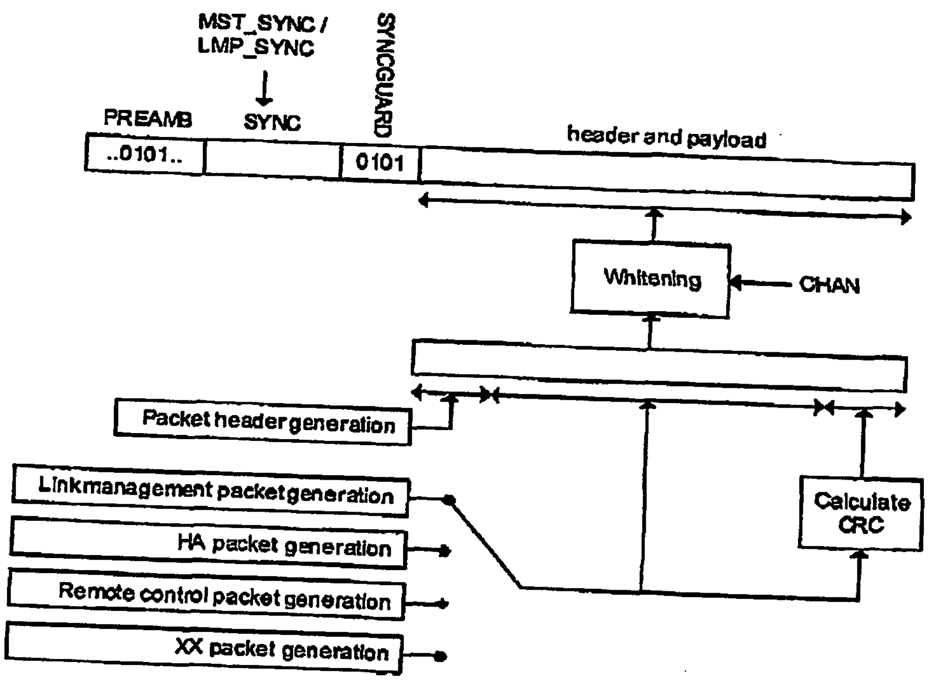

Fig. 5

5/11

Patent- og
Varemærkestyrelsen

06 JUNI 2003

Modtaget

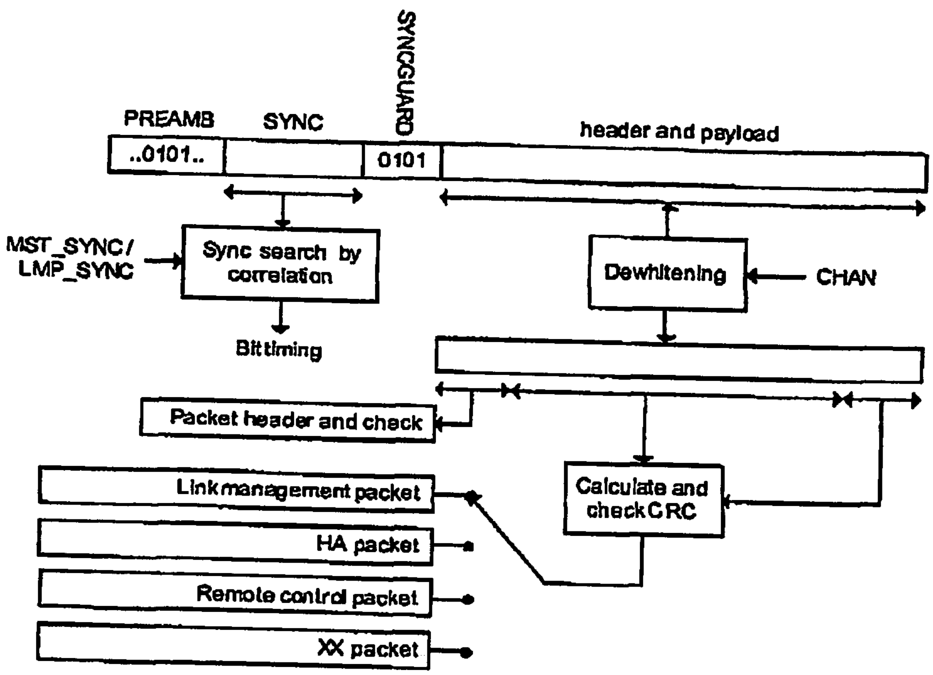

Fig. 6

Patent- og
Varemærkestyrelsen
06 JUNI 2003
Modtaget

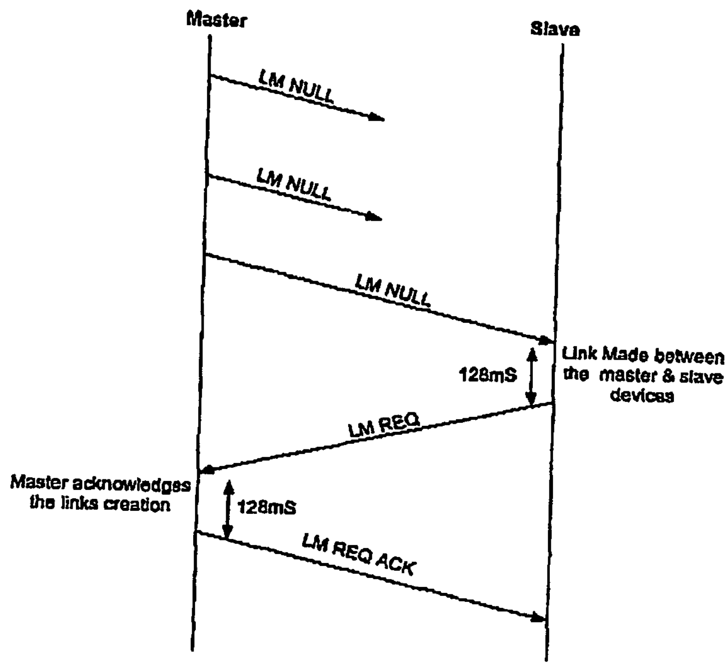

Fig. 7

Patent- og
Varemærkestyrelsen
06 JUNI 2003
Modtaget

7/11

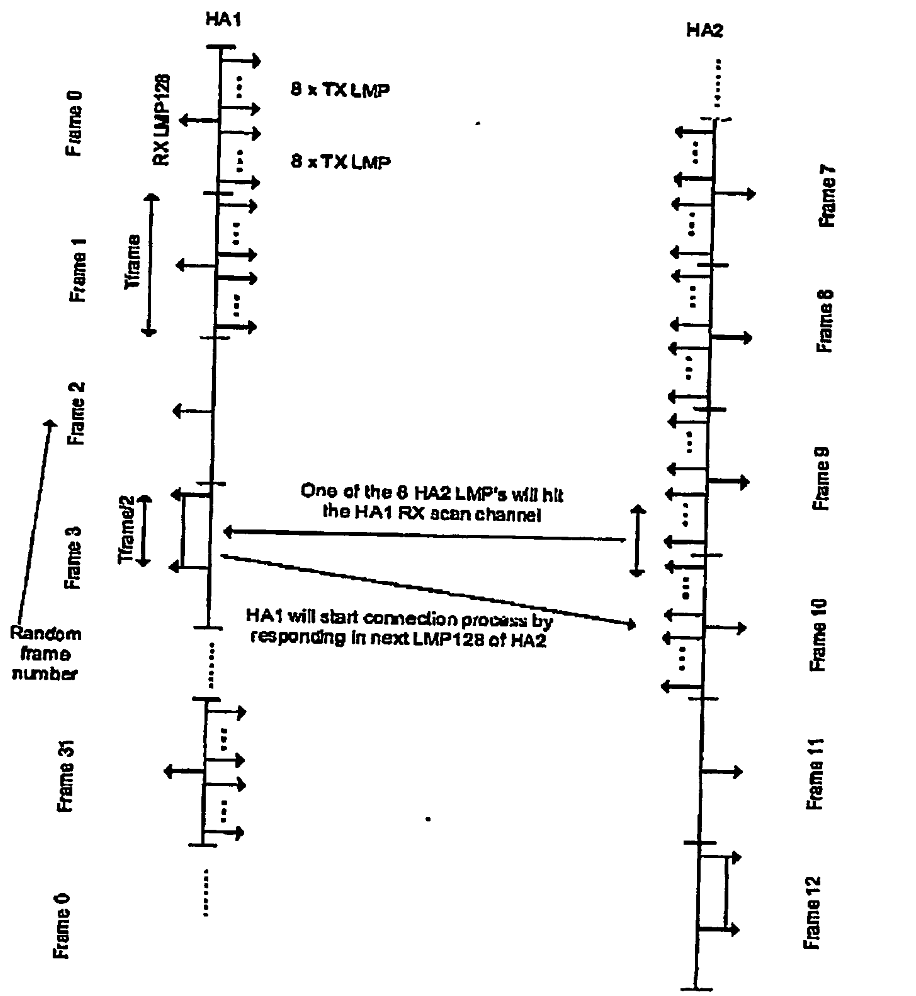

Fig. 8

Patent- og
Varemærkestyrelsen
06 JUNI 2003
Modtaget

8/11

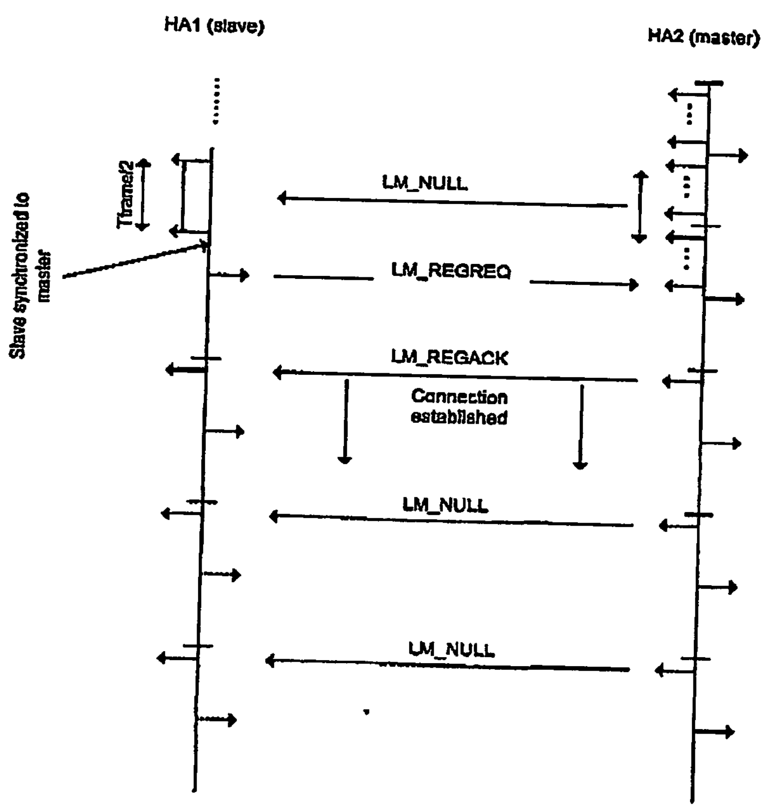

Fig. 9

Patent- og
Varemærkestyrelsen
06 JUNI 2003
Modtaget

9/11

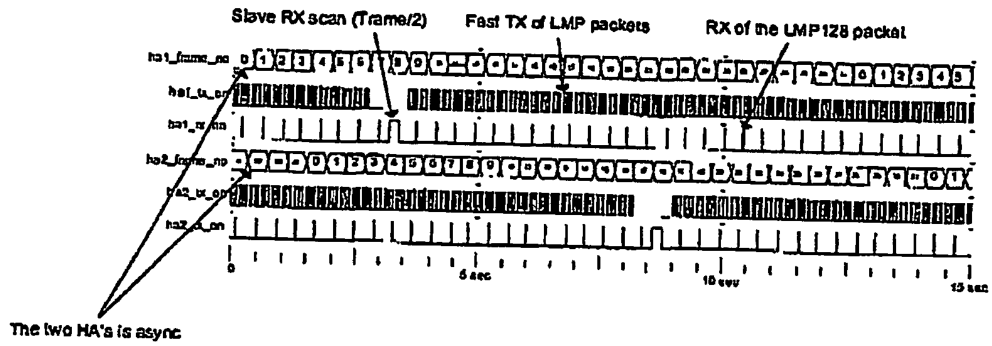

Fig. 10

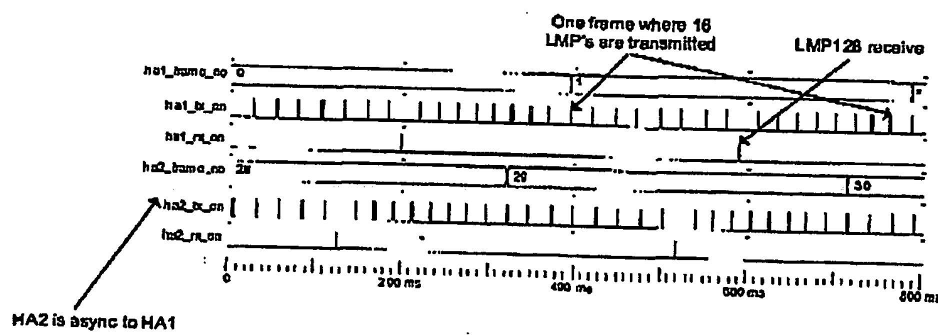

Fig. 11

Patent- og
Varemærkestyrelsen
06 JUNI 2003
Modtaget

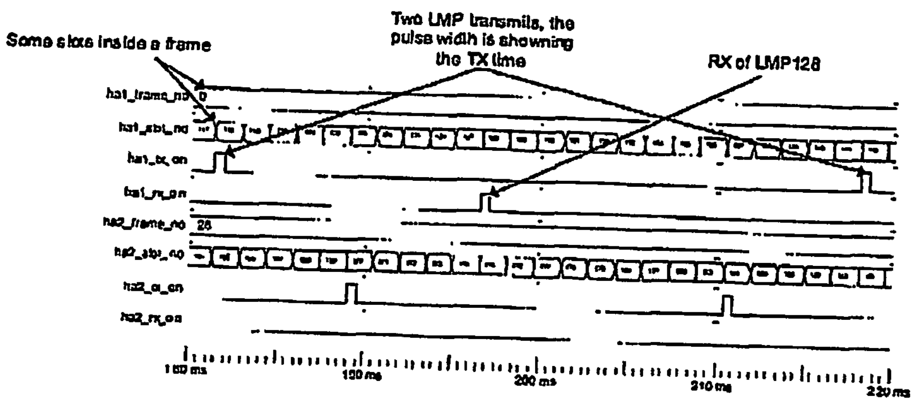

Fig. 12

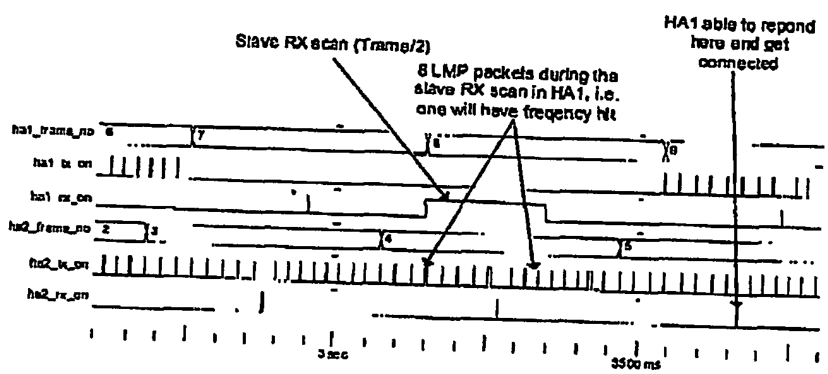

Fig. 13

Patent- og
Varemærkestyrelsen

06 JUNI 2003

Modtaget

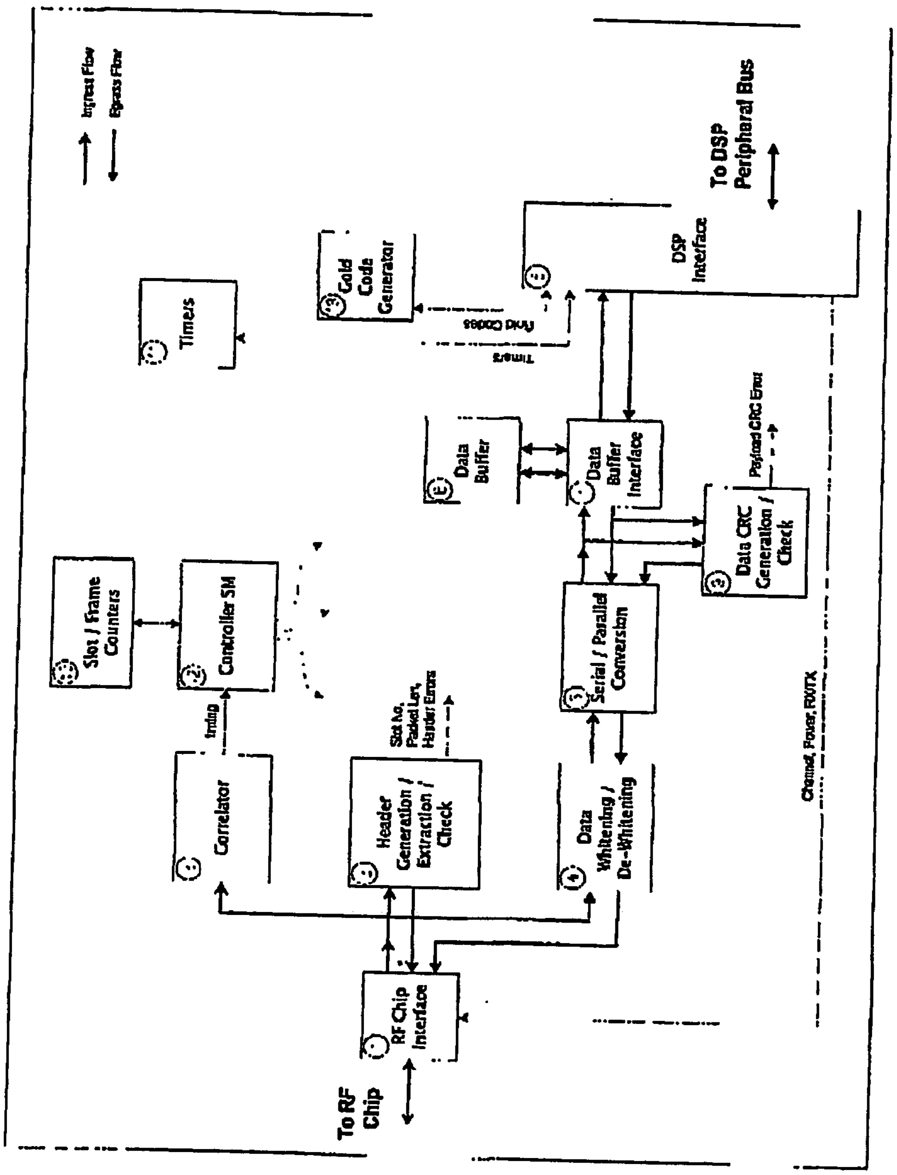

Fig. 14

This Page is Inserted by IFW Indexing and Scanning Operations and is not part of the Official Record

BEST AVAILABLE IMAGES

Defective images within this document are accurate representations of the original documents submitted by the applicant.

Defects in the images include but are not limited to the items checked:

- ☐ BLACK BORDERS
- ☐ IMAGE CUT OFF AT TOP, BOTTOM OR SIDES
- ☑ FADED TEXT OR DRAWING
- ☐ BLURRED OR ILLEGIBLE TEXT OR DRAWING
- ☐ SKEWED/SLANTED IMAGES
- ☐ COLOR OR BLACK AND WHITE PHOTOGRAPHS
- ☐ GRAY SCALE DOCUMENTS
- ☑ LINES OR MARKS ON ORIGINAL DOCUMENT
- ☐ REFERENCE(S) OR EXHIBIT(S) SUBMITTED ARE POOR QUALITY
- ☐ OTHER: ______________________________

IMAGES ARE BEST AVAILABLE COPY.
As rescanning these documents will not correct the image problems checked, please do not report these problems to the IFW Image Problem Mailbox.